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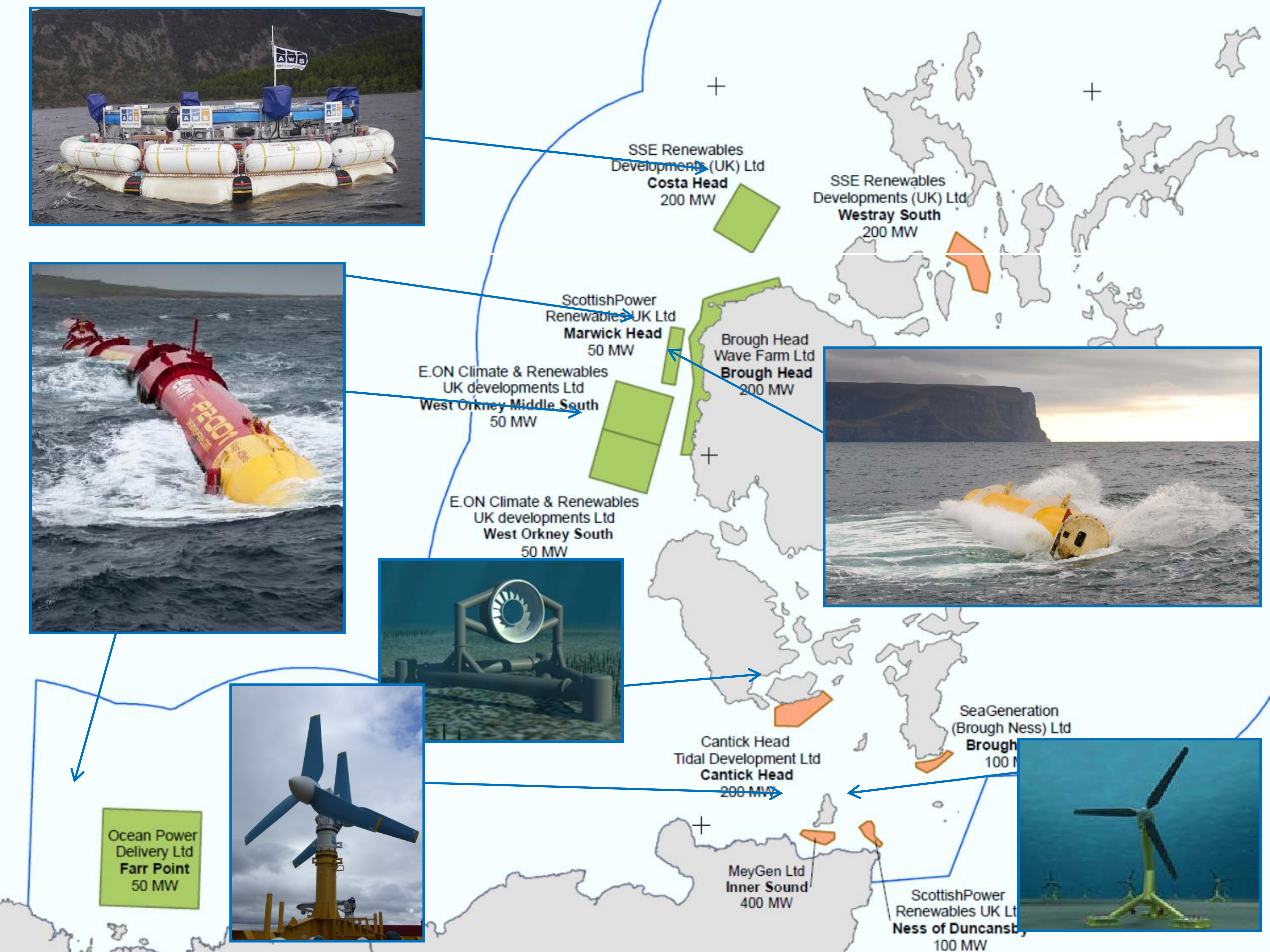
Implementation of Tidal Energy Extraction in a Finite Volume Coastal Ocean Model

NERC Marine Renewable Energy Knowledge Exchange Programme 2014

Partner: Marine Scotland Science (MSS), Aberdeen

Supervisors: Dr Rory O'Hara Murray (MSS) and Dr Rob Harris (ICIT)


SSE Renewables Developments (UK) Ltd
Costa Head
200 MW
SSE Renewables Developments (UK) Ltd
Westray South
200 MW
ScottishPower Renewables UK Ltd
Marwick Head
50 MW
Brough Head Wave Farm Ltd
Brough Head
200 MW
E.ON Climate & Renewables UK developments Ltd
West Orkney Middle South
50 MW
E.ON Climate & Renewables UK developments Ltd
West Orkney South
50 MW
SeaGeneration (Brough Ness) Ltd
Brough
100
Cantick Head Tidal Development Ltd
Cantick Head
200 MW
Ocean Power Delivery Ltd
Farr Point
50 MW
MeyGen Ltd
Inner Sound
400 MW
ScottishPower Renewables UK Lt
Ness of Duncansb
100 MW

MSS Oceanography Group's role in MRE

- One role of the Oceanography Group is to provide the scientific expertise to
  - Advise our Licensing colleagues about oceanographic aspects relevant to the licensing process (e.g. development license applications)
  - Assess the availability of MRE resources (tides, waves)
  - Quantify the potential impact of MRE developments (tidal, waves and offshore wind) on the physical environment

Personal background

Solid constitutive modelling
- structured cohesive soil
- unsaturated soil: multiphase continuum
- continuum thermomechanics:
  - free energy, internal state variables
  - invariance, objectivity
- material nonlinearity

Numerical methods
- explicit Runge-Kutta for state-based IVPs:
  - seismic structural dynamics
  - constitutive update
- multidimensional nonlinear minimization:
  - model parameter estimation

Structural dynamics
- seismic performance of frame structures:
  - geometric and material nonlinearity
- finite deformation of flexible shells:
  - kinematics

Model construction using Tensor methods

Programming
- structured/modular design:
  - high quality
  - suitable for research
- computationally efficient, robust

Computational fluid dynamics
- curvilinear, non-orthogonal coordinates
- depth-averaged tidal flow and transport

Mathematics
- pure, axiomatic, rigorous, abstract
- linear algebra
- differential calculus on normed vector spaces

Marine Renewable Energy

Background

- Oceanography Group at Marine Scotland Science (MSS): potential impacts of marine renewable energy developments
- Computational hydrodynamic models are the only way to obtain detailed flow information
- Finite Volume Method: the flow domain is subdivided into a finite number of discrete cells; the continuous flow field is represented by a finite set of values
- Discretized balance equations are solved numerically: accuracy, mesh dependency, stability, computational efficiency

Marine Renewable Energy

Background

- Model simulation of coastal ocean flows requires considerable expertise: problem definition, data input, interpretation of the results
- Modelling of tidal stream energy extraction is relatively new: limitations of different modelling approaches and validity of numerical simulations with respect to future energy extraction scenarios, are largely unknown
- Different scales of motion: small-scale flows (turbulence and swirl) may be significant for environmental processes (transport of sediment and nutrients), but with a relatively minor effect on energy resource

Implementation of Tidal Energy Extraction in a Finite Volume Coastal Ocean Model:

Objectives

- Rational approach to the assessment of numerical simulations: continuum balance equations; numerical approximation
- Basis for comparison of different modelling studies
- Physical principles governing energy extraction in general
- Specific details for the Finite Volume Coastal Ocean Model (FVCOM)
- Flexible user facility for the representation of tidal turbines
- Allow for future model development: swirl and turbulence; turbine control strategies

Implementation of Tidal Energy Extraction in a Finite Volume Coastal Ocean Model

Activities

- 3D modelling: sigma-coordinates: additional resistance has to be represented over the appropriate region of the water column
- 2D modelling : vertically-integrated balance equations: flow resistance may be treated as locally enhanced bed roughness
- 1D modelling: cross-channel integration; each cross-section is represented as a point in a 1D domain
- 1D model derivation gives insight into integration process inherent in discrete models general: second order variations give rise to ‘Reynolds stresses’ and similar terms (not necessarily turbulent)
- Gives insight into the fundamental nature of discrete model equations, as ‘filtered’ forms of the continuum equations

Implementation of Tidal Energy Extraction in a Finite Volume Coastal Ocean Model

Activities

- Idealized channel model: broadly representative of the Pentland Firth; study a range of conditions and energy extraction scenarios
- Compare results with 1D model applied to the same problem: use the comparison to illustrate capabilities and limitations of simple models
- Clarify the mathematical foundations: continuum balance, discretization, coordinate systems; simple and clear formulation, allowing for a consistent and rigorous comparison of different models
- Investigate and document the structure of the FVCOM source code: clarify details of solution algorithms; learn how best to implement new features
- Literature review: tidal stream energy extraction in particular; computational and mathematical techniques in general

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Benefits of the Experience

- Sharp practical focus for application of abstract mathematical approach of my PhD studies (sub-mesoscale tidal flow modelling and the effects of tidal stream energy extraction)
- Regular close contact with my supervisor Dr O’Hara Murray
- Informal discussions with staff and students at MSS
- Group seminars and meetings
- MSS library
- Aberdeen University: lectures and library access
- St Andrews University: Scottish Fluid Mechanics Meeting

Implementation of Tidal Energy Extraction in a Finite Volume Coastal Ocean Model

Benefits to MSS

- Systematic and rigorous approach to the question of modelling in general: detailed technical report helpful to others engaged in similar work
- Basis for objective assessment of merits and limitations of various modelling studies
- Improved understanding of detailed internal workings of FVCOM: modelling issues, practical solutions
- Closer working links with Heriot-Watt University: better communication, awareness of future collaboration potential

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Ongoing and Future Work

- 3D energy extraction model development is ongoing. This is a crucial part of the MSS modelling system in respect of future assessments
- Basic facility is restricted to linear momentum effects. Subsequent PhD work will build on this by modelling other processes: swirl, turbulence, mixing
- Potential for improvements in computational efficiency: adaptive numerical methods with error estimation